Transphyseal reconstruction of the anterior cruciate ligament in prepubescent children

A. D. Liddle, A. M. Imbuldeniya, D. M. Hunt

From St Mary's Hospital, London, England

We present the results of 17 children of Tanner stage 1 or 2 who underwent reconstruction of the anterior cruciate ligament between 1999 and 2006 using a transphyseal procedure, employing an ipsilateral four-strand hamstring graft. The mean age of the children was 12.1 years (9.5 to 14). The mean follow-up was 44 months (25 to 100). Survival of the graft, the functional outcome and complications were recorded. There was one re-rupture following another injury. Of the remaining patients, all had good or excellent results and a normal International Knee Documentation Committee score. The mean post-operative Lysholm score was 97.5 (SD 2.6) and the mean Tegner activity scale was 7.9 (SD 1.4). One patient had a mild valgus deformity which caused no functional disturbance. No other abnormality or discrepancy of leg length was seen. Measurements with a KT1000 arthrometer showed no significant difference between the normal and the operated legs.

In this small series, transphyseal reconstruction of the anterior cruciate ligament appeared to be safe in these young children.

Injuries to the anterior cruciate ligament (ACL) in children were once thought to be rare, but have been described more prominently in the literature since the 1970s. Increasing participation in sport from a young age, together with advances in imaging, have resulted in a much greater frequency of diagnosis. Controversy remains as to the best form of treatment for such injuries in this age group. The apparent ineffectiveness of conservative treatment and the perceived dangers of reconstructive surgery have led to much debate. Primary repair, delayed reconstruction or techniques sparing the physis have all been described with varying degrees of success, but an increasing body of evidence suggests that conventional reconstruction of the ACL is safe and effective. However, in these studies most of the children have had a chronological age above 12 years, or a biological stage of 3 to 4 by the criteria of maturity described by Tanner and Whitehouse. We present the results of transphyseal reconstruction of the ACL using a four-strand hamstring tendon graft, in children of Tanner stage 1 and 2.

Patients and Methods

Between 1999 and 2006, 17 prepubescent patients (Tanner stage 1 or 2, Table I) underwent unilateral reconstruction of the ACL. There were three girls and 14 boys, with a mean chronological age of 12.1 years (9.5 to 14.0) at the time of operation. Symptoms of instability occurred following an accident in one patient and a sporting injury in 16. The latter occurred while playing rugby football in six, association football in four, skiing in three, trampolining in one and during free play in two. One patient had undergone a previous ipsilateral arthroscopic meniscectomy, during which the injury to the ACL was diagnosed. None of the remainder had undergone any previous surgery to the knee.

Pre-operative work-up. All patients were assessed pre-operatively by clinical examination, which included the pivot shift, anterior drawer and Lachman’s test. Anteroposterior and lateral radiographs of the knee were taken during weight-bearing. Function was assessed by completion of the Lysholm knee score and Tegner activity scale. All patients had pre-operative MRI to confirm rupture of the ACL and to diagnose meniscal injury.

The Tanner stage was confirmed by the senior author after the induction of general anaesthesia. Of the 17 patients, eight were stage 1 and nine stage 2 (Table II).

Operative technique. All patients had an arthroscopically-assisted transphyseal reconstruction of the ACL using an autologous ipsilateral four-strand hamstring tendon graft (Fig. 1). All the operations were performed by the senior author.
The procedure was carried out with the patient supine, under general anaesthesia, using a pneumatic tourniquet. Under anaesthesia, examination of the knee confirmed the diagnosis of anterior cruciate instability. An arthroscopy was then performed via standard lateral and medial ports. At this point, any concomitant meniscal pathology was treated by meniscal repair or meniscectomy as appropriate. The stump of the ACL was identified and debrided. A notch-plasty was performed as judged necessary.

A longitudinal incision of 2 cm to 3 cm was made over the anterior tibia, medial to the tibial tubercle. The pes anserinus was identified, and the gracilis and semitendinosus tendons dissected out by a combination of blunt and sharp dissection before being removed with a tendon stripper. The two tendons were attached together by means of a whip-stitch at each end. The combined graft was then threaded through the closed loop of an Endobutton (Smith & Nephew, Andover, Massachusetts), doubled over, and the diameter measured.

The Acufex Protrac tibial guide (Smith & Nephew) was used to introduce a guidewire from the anterior tibia into the tibial plateau, exiting just anterior to the posterior cruciate ligament. The femur was then drilled to the same size as the graft, deep enough to allow the Endobutton to be threaded through and flipped. These tunnels were created slowly to minimise the risk of thermal damage to the growth plate.

The graft, mounted on the Endobutton, was introduced into the tibial tunnel and passed across the knee and through the femoral tunnel. The Endobutton was then flipped, and the knee flexed and extended to pre-tension the graft. The tibial end of the graft was secured under tension at 20° of knee flexion, using a screw and washer (Acufex, Smith & Nephew) transversely across the tibia, distal to the growth plate. Interference screws alongside the graft were avoided as they could reach the growth plate. The stability of the knee was examined and the graft inspected for impingement of the notch.

Post-operative regimen. The children were mobilised fully weight-bearing on the first day after operation. A brace was not used routinely. Radiographs of the knee were obtained to check the position of the tunnels and fixation. A standard rehabilitation programme followed, taken more slowly than in adults. All children were seen regularly, with
formal assessment at six months, one year, and then annually until at least the completion of growth. The Lysholm knee score,\textsuperscript{17} the Tegner activity scale \textsuperscript{18} and the International Knee Documentation Committee (IKDC)\textsuperscript{16} knee ligament standard evaluation scores were recorded. Statistical comparison of the scores before injury, and before and after operation was by Wilcoxon’s signed ranks test.

The objective stability of the knee was measured using the KT1000 arthrometer (MEDmetric Corporation, San Diego, California).\textsuperscript{19} All the children were examined clinically for swelling, muscle wasting, range of movement, varus and valgus deformity, leg length and stability.

Results
The children were followed for a minimum of two years, with a mean of 44 months (25 to 100). Of the 17 children, ten had associated meniscal injuries. One of the latter had an arthroscopic meniscectomy before the repair of the ACL, two a meniscal repair at the same time as the ACL reconstruction, and the remainder had a concurrent meniscectomy and repair of the ACL.

There were two complications. One child had a rupture following a playground injury eight months after surgery. The other required antibiotics for a wound infection overlying the tibial screw.

Of the 16 children with successful reconstructions, 15 (93.75\%) had an excellent result and one (6.25\%) a good result after two years. The mean Lysholm score at follow-up was 97.5 (SD 2.6) compared to 71.1 (SD 8.7) preoperatively (p = 0.0004). The mean Tegner activity scale was 8.1 (SD 0.8) before injury, 4.2 (SD 1.0) after injury, and 7.9 (SD 1.4) at follow-up, indicating a significant improvement between before and after operation (p = 0.0004), and no statistically significant difference between that before injury and that after operation (p = 0.5366).

All patients had a full range of movement in both knees. There was no leg-length discrepancy either clinically or radiographically. One patient had a valgus deformity of 5° on the operated side. This was not apparent to the patient or his parents, and caused no functional disturbance. Radiographs showed that there was no damage to the growth plate or formation of a physeal bar. None of the patients had ongoing symptoms. One complained of occasional feelings of instability, but there was no restriction of activity and the clinical examination was normal. All patients were normal according to the IKDC ligament evaluation form.

The KT1000 arthrometer scores were recorded as millimetres of anterior displacement with 15 lb, 20 lb and maximal manual force applied. The results are shown in Table III. There was no significant difference between the two groups in any of the three measurements (p = 1.0, p = 0.8, p = 0.56, respectively). Only one reading in one patient was outside the margin of error of the arthrometer, which was 2 mm. In patient 9 there was a 3 mm difference in the maximal force reading.

There was no evidence on the radiographs to suggest that the fixation had jeopardised the growth plates.

Discussion
Although reconstruction is the accepted treatment for injuries to the ACL in adults, it remains a controversial procedure in children. Mid-substance injury to the ACL has been thought rare in this age group. The attachment of the ligament blends with the epiphyseal cartilage and hence an avulsion fracture of the tibial spine was more frequently seen than a mid-substance tear.\textsuperscript{1,20,21}

Over the last decade, mid-substance injuries to the ACL in children have been described more frequently, and now appear to be more common than avulsion fractures of the tibial spine.\textsuperscript{22} Between 0.5\%\textsuperscript{23} and 3\%\textsuperscript{24} of injuries to the ACL occur in children and constitute 3\% of injuries to the knee in paediatric patients.\textsuperscript{25} Traumatic haemarthrosis in children has been attributed to rupture of the ACL in 29\%\textsuperscript{26} to 47\%\textsuperscript{27} of cases. The apparent increase in the incidence of this injury has been attributed to an increased participation in sporting activities among the young, but the introduction of MRI and arthroscopy may partially account for the increased frequency of this diagnosis.\textsuperscript{28,29}

The conservative treatment of these injuries has been consistently associated with poor outcomes, including progressive instability, meniscal injuries and osteoarthrosis. Aichroth, Patel and Zorrilla\textsuperscript{30} followed 23 patients managed conservatively for six years, by which time all had instability and ten had signs of arthrosis. Other studies have also shown high rates of further meniscal injury\textsuperscript{3,31,32} and instability in the longer term.\textsuperscript{4} Woods and O’Connor\textsuperscript{10} achieved a good
outcome in 13 patients treated by strict limitation of activity, bracing, extensive counselling of patient and parents, and absolute abstention from sport at school. All patients then had a reconstruction of the ACL at skeletal maturity.

Primary repair of the ligament has been shown to give poor results, as has extra-articular tenodesis. Small series of combined intra- and extra-articular techniques, physeal sparing and partial transphyseal approaches have

<table>
<thead>
<tr>
<th>Patient</th>
<th>Tegner activity</th>
<th>Lysholm score</th>
<th>History and clinical examination</th>
<th>KT1000 score: difference between legs</th>
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<td>Swelling LLD Deformity ROM</td>
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<td>8</td>
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<td>2</td>
<td>8</td>
<td>4</td>
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<td>8</td>
<td>4</td>
<td>10</td>
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<td>10</td>
<td>3</td>
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<td>4</td>
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<td>80 95 Excellent Nil Nil Nil Nil Full B B A 0 0 0</td>
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<td>8</td>
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<td>4</td>
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<td>75 95 Excellent Nil Nil Nil Nil Full A A A 0 0 0</td>
</tr>
</tbody>
</table>

Patient 13 suffered a re-rupture at eight months and is therefore not included in this table.

* LLD, leg-length discrepancy; ROM, range of movement; IKDC, International Knee Documentation Committee subjective knee score
† KT15, anterior displacement (mm), with 15 lb of force; KT20, anterior displacement (mm) with 20 lb of force; KTmax, anterior displacement (mm) with maximal manual force, all measured using the KT1000 arthrometer

Table IV. Anterior cruciate ligament reconstruction series

<table>
<thead>
<tr>
<th>Author/s</th>
<th>Patients</th>
<th>Age range (yrs)</th>
<th>Mean follow-up (mths)</th>
<th>Failure</th>
<th>Complications</th>
<th>Technique</th>
<th>Outcome</th>
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<td>12 to 15</td>
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<td>1</td>
<td>Hamstrings + extra-articular*</td>
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<td>McCarroll et al34</td>
<td>60</td>
<td>13 to 17</td>
<td>50</td>
<td>3</td>
<td>0</td>
<td>Bone</td>
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<td>Lo et al39</td>
<td>6</td>
<td>8 to 14</td>
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<tr>
<td>Matava and Siegel48</td>
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<td>Mean 14.9</td>
<td>32</td>
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<td>25</td>
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<td>0</td>
<td>Achilles</td>
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<td>Edwards et al46</td>
<td>21</td>
<td>11.8 to 15.6</td>
<td>34</td>
<td>3</td>
<td>0</td>
<td>B-PT-B or hamstrings</td>
<td>Excellent</td>
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<tr>
<td>Aichroth et al50</td>
<td>47</td>
<td>11 to 15</td>
<td>49</td>
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<td>0</td>
<td>Hamstrings</td>
<td>Good</td>
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<td>Fuchs et al45</td>
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<td>9 to 15</td>
<td>40</td>
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<td>B-PT-B</td>
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<tr>
<td>Anderson40</td>
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<td>10 to 14.6</td>
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<td>0</td>
<td>Hamstrings</td>
<td>Excellent</td>
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<tr>
<td>Shelbourne et al44</td>
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<td>41</td>
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<td>0</td>
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<td>Excellent</td>
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<tr>
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<td>12.3 to 14.3</td>
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<td>0</td>
<td>Hamstrings</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

* in Lipscomb’s 1986 series, reconstructions was performed using hamstrings supplemented by extra-articular stabilisation using the Losee or Ellison techniques
† B-PT-B, Bone-patellar tendon-bone
‡ the 19 patients from this paper are re-reported in Sankar’s 2008 survival analysis
§ Sankar’s paper is a survival analysis based on telephone interview, thus complications cannot be accurately assessed
been described with encouraging results, but these procedures are challenging, with a small margin for error, and in most cases the reconstruction is non-anatomical.36-40

Transphyseal repair, as used in adults, has been approached with caution owing to the continuing concerns about damage to the growth plate, with the possible consequence of discrepancy in leg length and angular deformity. The survey by Kocher et al5 of the ACL study group found 12 cases of growth disturbance in transphyseal reconstructions and three in other types of repair. All but one were attributed to the use of excessively large tunnels, or to metal or a bone plug crossing the growth plate. The remaining child was a girl aged 11 years who required epiphysiodesis for overgrowth of 30 mm on the operated side. Koman and Sanders41 noted a severe valgus deformity in a boy aged 14 years as a result of the interference screw crossing the growth plate. Lipscomb and Anderson’s24 series of 24 patients included one with retardation of growth of 20 mm on the operated side which was attributed to staple fixation over both the tibial and the femoral physes. However, there are now many studies showing the safety of transphyseal reconstruction in the skeletally immature, but most are in older children8,24,30,39,40,42-52 (Table IV).

The effect of instrumentation on the growth plate has been extensively studied in animal models. Langenskiöld53 demonstrated that interposition of soft tissue into physeal defects prevents the formation of bony bars and subsequent delay in growth. This is analogous to placing the hamstring graft across the physis in reconstruction of the ACL. Nordentoft54 showed that a tunnel size of 20% of the transverse diameter of the femoral growth plate, or about 7% of the area of cross-section can be drilled without damage. Edwards et al55 showed that excessive tensioning of grafts led to growth disturbance without formation of a physeal bar. The use of larger tunnels and interposition of screws or bone graft can cause growth retardation with formation of such bars.56

Previous clinical studies have shown no reduction in the range of movement as the patient grows, implying that the grafts grow to maintain their size relative to the patient.30 A recent study examining the MRI appearances of reconstructions of the ACL in skeletally-immature patients demonstrated dramatic lengthening of the graft together with expansion of the bone tunnels.52 Our observations agree with these findings (Fig. 2).

On the basis of this preliminary study, anterior cruciate ligament reconstruction by transphyseal four-strand hamstring graft appears to be a reasonable management option in the prepubescent patient.

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References